

Pappus morphology and terminology in Australian and New Zealand thistles (Asteraceae, tribe Cardueae)

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Summary

Bean, A.R. (2001). Pappus morphology and terminology in Australian and New Zealand thistles (Asteraceae, tribe *Cardueae*). *Austrobaileya* 6 (1) 139–152. 23 pappus characters (including several newly recognised) and five achene characters have been used to compile comprehensive morphological descriptions for 30 species of mostly naturalised thistles occurring in Australia and New Zealand. This represents the first detailed English account of pappus morphology for tribe *Cardueae*. Some new pappus terminology for the tribe is introduced, and standardised definitions are suggested. A key to the described species is provided, based on pappus and achene morphology only.

Key words: Asteraceae, Compositae, pappus, morphology, terminology, thistles, Australia, New Zealand, tribe *Cardueae*.

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Introduction

The morphology of pappus in the Asteraceae is very useful taxonomically, as it offers a wealth of characters.

Dittrich presented a comprehensive account of fruiting morphology, covering numerous genera of the subtribes *Centaureinae* (Dittrich 1968) and *Carduinae* (Dittrich 1970). He also provided keys to genera based solely on achene and pappus characteristics. Petit (1997), in his cladistic analysis of the whole of the *Cardueae*, included further salient observations about pappus and achene morphology. Few other workers have paid much attention to the diversity of carduine pappus morphology.

Members of Asteraceae tribe *Cardueae* (*sensu* Bremer 1994), commonly known as the “thistles”, are well represented in Australia (with c. 32 species in 15 genera) and New Zealand (with c. 21 species in 9 genera (Garnock-Jones 1988)). These all belong to either subtribe *Carduinae* or subtribe *Centaureinae*. Most are naturalised and originate from Europe. Australia has two indigenous species (*Hemisteptia lyrata* and *Stemmacantha australis*), while New Zealand is without indigenous species.

This paper, the first of its kind in English, documents further details of pappus morphology not recorded by Dittrich (*loc. cit.*) or Petit (*loc. cit.*), and provides definitions for several terms (some new, some already established) as they apply to tribe *Cardueae*. It provides comprehensive, directly comparable measurements and observations of pappus characters for the great majority of Australian and New Zealand species, as well as a few obvious features of the achenes. A dichotomous key to these taxa is provided using only pappus and achene characters.

It is hoped that this paper will provide some impetus for a more wide-ranging study of pappus morphology, and that others will attempt to improve the standardisation of pappus terminology in this and other tribes of Asteraceae.

Materials and methods

30 taxa have been included in this study. Specimens from all major Australian herbaria and from Christchurch (CHR) in New Zealand have been examined (Appendix 1), using a light microscope (x 40) with graticule.

2–5 specimens per taxon were used, at least two pappi and two achenes were measured per specimen, and 23 pappus characters and 5 achene characters were recorded for each pappus and achene.

Proposed definitions for Tribe Cardueae

A plethora of terms have been used to describe Asteraceae pappus, viz. scale, seta, bristle, paleaceous, capillary, scabrid, plumose, barbellate, filamentous etc. Many of these terms are listed and loosely defined by Jackson (1928), but a lack of definition has resulted in a variety of terms being used for what amounts to the same structure, or conversely the one term has been applied to a wide range of structures. For this reason, appropriate pre-existing terms have been selected here, and more explicitly defined, to allow uniformity of interpretation, while reinforcing common usage. Also, a number of new terms have been introduced.

These definitions have been applied to members of tribe *Cardueae* only, and it should be realised that some of them may not be readily applicable to other tribes in Asteraceae.

- a). The term “**monomorphic pappus**” is used for a pappus where all the elements are the same or similar, or they vary in length or width only (e.g. Fig. 1A). The term “**dimorphic pappus**” is used where there are two distinct types or groups of pappus elements forming an entire whorl or partial whorl (e.g. Fig. 1E). They must be discernible by position, orientation or major morphological trait. Discordant elements within a whorl e.g. the few long broad bristles in *Onopordum acanthium*, are not considered sufficient to constitute a distinct pappus type.
- b). A “**pecten**” (plural “**pectines**”) is the term used here for the regularly or irregularly spaced antrorse side-branches (or lateral projections) of a bristle. They are formed by an extension of the outer epidermal cells of the bristle (Fig. 1G, 1H).
- c). A “**bristle**” is defined here as a pappus element which is more than 5 times longer than wide, is parallel-sided or slightly tapered apically or at both ends, and possesses pectines. A bristle with a length exceeding 100 times its width (excluding pectines) is called a “**capillary bristle**” e.g. Fig. 2A; a bristle with a length 5-50 times its width (excluding pectines) is called an “**ensiform bristle**” e.g. Fig. 2J; any rigid or non-parallel-sided pappus element with or without pectines is called an “**awn**” e.g. Fig. 2M.
- d). A “**plumose**” bristle is one where the length of the average mid-bristle pecten is 10-30% of the (capillary) bristle length (e.g. Fig. 2F). In plumose bristles, the pectines are usually irregularly spaced. A “**sub-plumose**” bristle is one where the length of the average mid-bristle pecten is 2-10% of the bristle length. A “**barbellate**” bristle is one where the length of the average mid-bristle pecten is less than 2% of the bristle length (e.g. Fig. 2A). In barbellate bristles, the pectines are nearly always regularly spaced along the bristle.
- e). The term “**fibrillas**”, used by Petit (1997) is adopted here. Fibrillas are short, erect, uniseriate trichomes, often densely clustered, and borne on or near the top of the cylinder, forming the innermost pappus whorls in a few species (Fig. 1I).
- f). The “**cylinder**” (equivalent to the pappus-cover of Dittrich (1970)), is a smooth ring-like structure composed of pericarpal tissue, and readily detaching from the achene (Fig. 1F, 1I). The cylinder forms the connate base of the pappus in many species, and is apparently associated only with capillary bristles. The bases of bristles are individually obliquely inserted onto the outer face of the cylinder, unifying the entire pappus. In a few species with connate pappus, the cylinder is absent, and the bristles are merely fused together at their bases.

List of characters used for descriptions of Australian and New Zealand taxa

1. pappus present or absent. A few species of *Centaurea* lack a pappus. In *Carthamus tinctorius*, the pappus is infrequently present.
2. pappus monomorphic or dimorphic. A term of convenience which does not indicate relationship. For example, the dimorphic pappus of *Silybum* is clearly not homologous with that of *Carthamus*.
3. number of whorls in pappus.

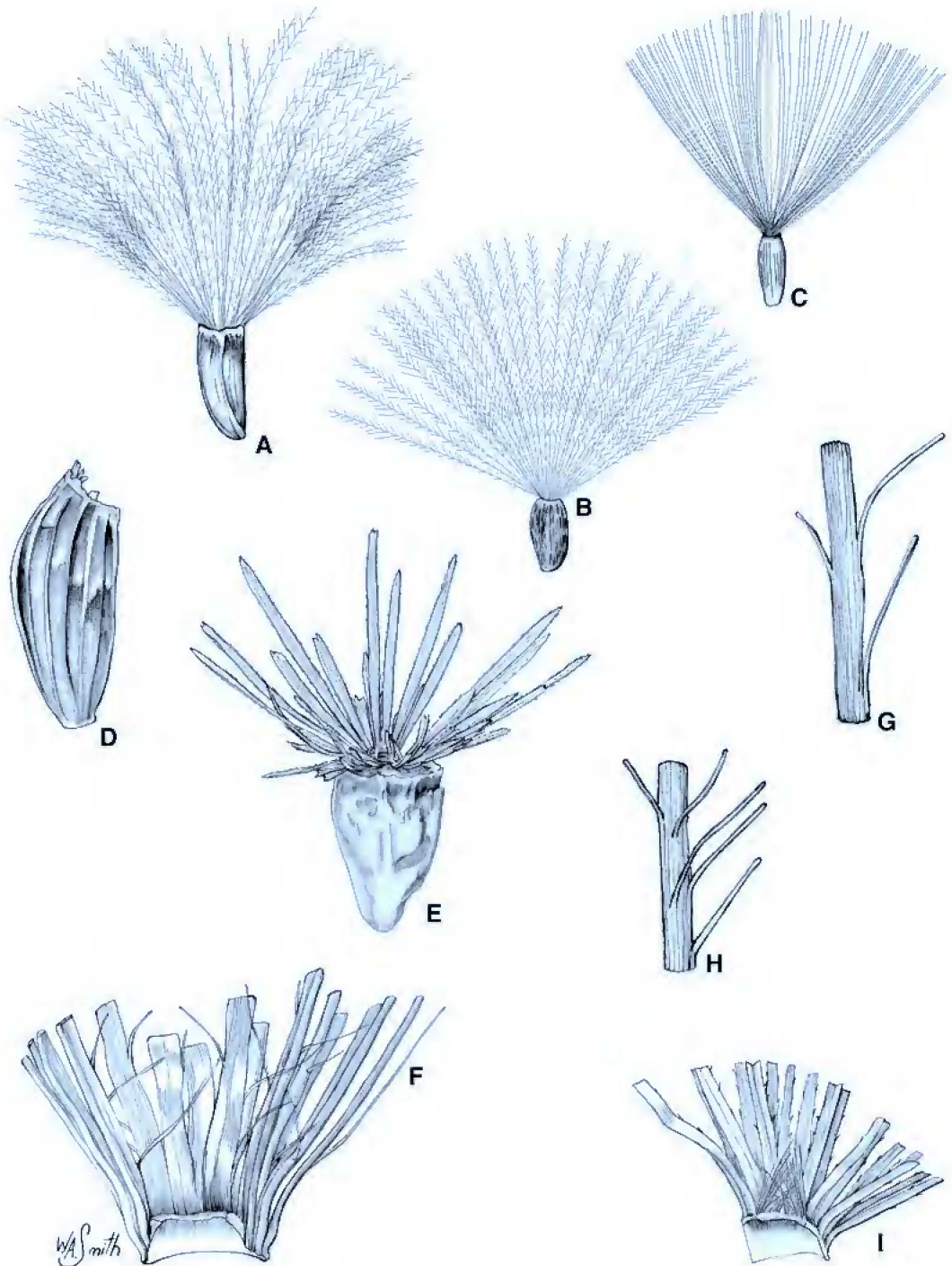


Fig. 1. A–C. Achene and pappus of various species $\times 2$ (A. *Stemmactantha australis*, B. *Picnoman acarna*, C. *Carduus pycnocephalus*). D. achene of *Hemisteptia lyrata* showing persistent ensiform bristles on outer edge $\times 12$. E. achene and pappus of *Carthamus lanatus*, some bristles removed to reveal inner whorl $\times 4$. F. basal portion of pappus of *Cirsium vulgare*, showing cylinder, and bristles inserted at different points $\times 24$. G–H. insertion of pectines. G. lateral only (*Cirsium vulgare*) $\times 48$. H. lateral and dorsal (*Hemisteptia lyrata*) $\times 48$. I. basal portion of pappus of *Silybum marianum*, showing cylinder and fibrillas $\times 12$. A, Bean 11348 (BRI); B, Tann s.n. (MEL); C, Bean 15601 (BRI); D, Bean 14133 (BRI); E, Blake 5164A (BRI); F,G, Dillewaard 590 & Stanley (BRI); H, K.McDonald s.n. (BRI); I, Bean 15829 (BRI). Del. W. Smith.

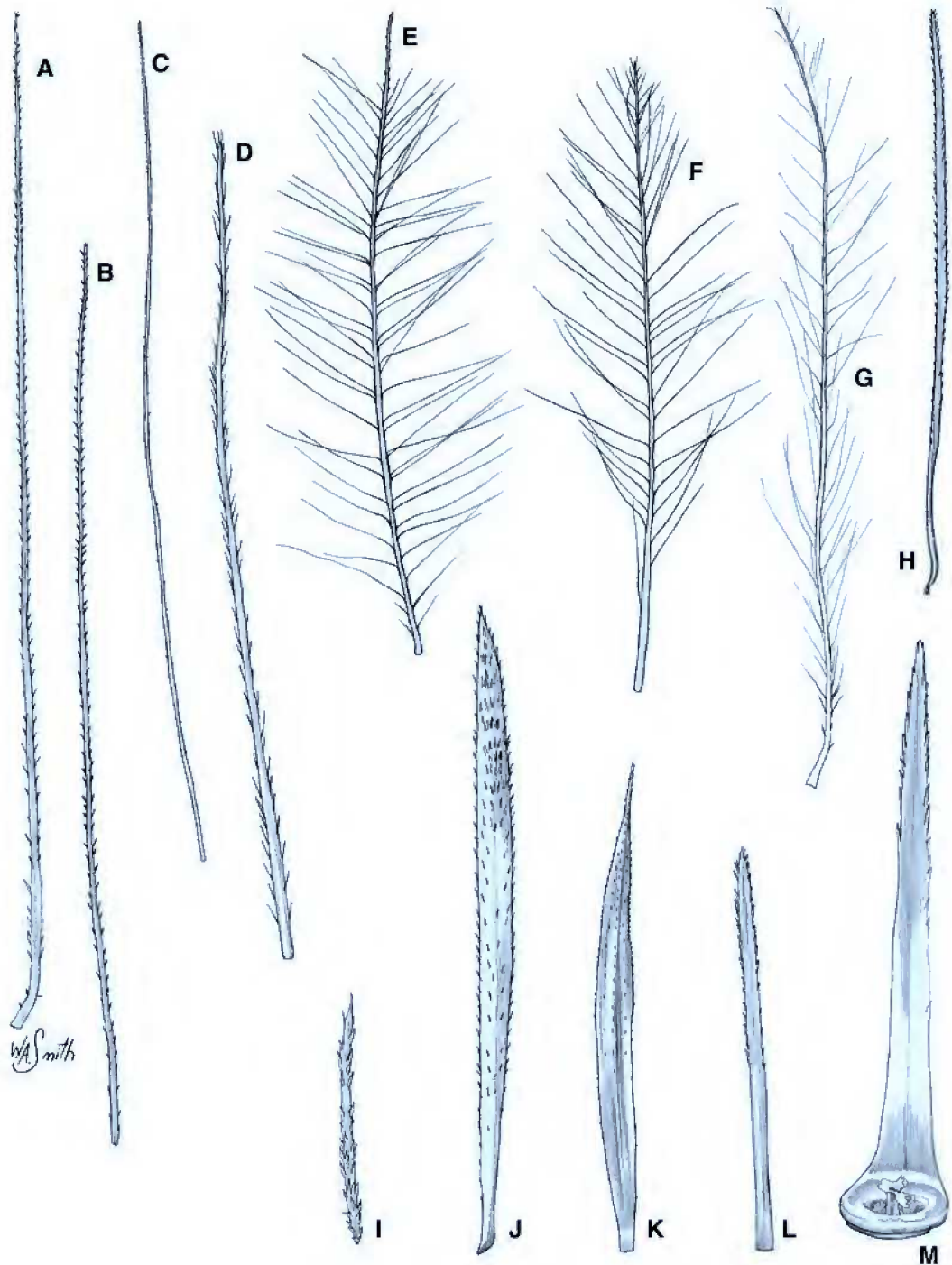


Fig. 2. Individual bristles of various species. A. *Carduus pycnocephalus* $\times 10$. B. *Carduus tenuiflorus* $\times 12$. C. *Carduus thoermeri* $\times 6$. D. *Onopordum illyricum* $\times 12$. E. *Picnomon acarna* (inner bristle) $\times 6$. F. *Picnomon acarna* (outer bristle) $\times 6$. G. *Hemisteptia lyrata* $\times 12$. H. *Centaurea melitensis* $\times 24$. I. *Arctium minus* $\times 24$. J. *Carthamus lanatus* $\times 12$. K. *Carthamus dentatus* $\times 6$. L. *Mantisalca salmantica* (bristle from outer pappus) $\times 24$. M. *Mantisalca salmantica* (inner pappus) $\times 24$. A, Bean 15738 (BRI); B, Whinray 607 (AD); C, Bean 15914 (BRI); D, Alcock 4977 (AD); E, F, Symon 2095 (AD); G, Jones 2908 (CANB); H, Bean 15890 (BRI); I, Grace s.n. (HO); J, Blake 5164A (BRI); K, Howlett s.n. (MEL); L, M, Bean 15637 (BRI). Del. W. Smith.

4. pappus element type (bristles or awns).
5. bristle type (capillary or ensiform).
6. number of bristles/awns per pappus.
7. pappus deciduous from achene or persistent.
8. pappus connate (bristles fused at their bases into a ring) or free (bristles individually attached to achene).
9. cylinder present or absent.
10. length of cylinder.
11. bristle whorls uniform or varying in length. When bristle whorls vary in length, it is apparently always the inner whorls that are longer.
12. 1–3 bristles within a whorl longer and thicker than remainder. This character was noted for *Onopordum* by Tamamschyan (1998).
13. bristle length (if varying, longer or longest whorls have been measured).
14. bristle width (excluding pectines). This is the width measured about half way along the bristle.
15. bristles expanded at base or not. This character applies only to the innermost whorl where an expanded spatulate bristle base occurs in some species (Dittrich 1968). The bristles otherwise taper gradually from proximal to distal end.
16. bristles not fasciculate or some bristles fasciculate. In *Onopordum acaulon*, some bristle pairs (or triplets) are laterally fused for one-fifth to one-half of their length.
17. pecten type - plumose, sub-plumose or barbellate.
18. bristles plumose throughout on all whorls, or with barbellate apical section (Fig. 2E, 2F). The inner whorls of a pappus bearing plumose capillary bristles often have a barbellate apical section, where the pectines are abruptly reduced. This section is often twisted or bent relative to the rest of the bristle, and may be slightly thickened. This character has been noted for *Cirsium* by Davis and Parris (1975) and by Charadze (1998).
19. length of barbellate apical section.
20. bristle apex. Generally acute; some ensiform bristles may have a toothed or obtuse apices.
21. pecten insertion. In some species, pectines are inserted only laterally onto the bristles (Fig. 1G). Some species also have pectines inserted onto the dorsal surface of the bristle (Fig. 1H). Rarely, pectines are inserted onto the ventral surface. Ventral pectines were noted for *Cynara* by Dittrich (1970) and Wiklund (1992).
22. pecten length. This is often relatively uniform, but where there is variability, pectines occurring about midway along bristle have been measured.
23. fibrillas absent or present (Fig. 1I). Fibrillas occur in only a few species. They were noted for *Silybum* by Dittrich (1970).
24. achene length. Measured along medial axis.
25. achene maximum width.
26. achene ribbing (longitudinally ribbed or transversely rugose or smooth).
27. achene indumentum. Glabrous or with sparse ciliate hairs.
28. apical rim. Absent in some species; otherwise entire, dentate or sinuate.

Pappus and achene descriptions for Australian and New Zealand taxa

Taxa are arranged in systematic order, following Petit (1997). These descriptions are based entirely on measurements of the specimens cited in Appendix 1. None has been augmented by descriptions given in Flora treatments or revisionary works.

(i) Subtribe Carduinae

1. *Hemistephia lyrata* (Bunge) Fisch. & C.A.Mey.

Pappus dimorphic. Inner pappus comprising one whorl of capillary bristles, 14–18 in number, deciduous, basally connate, cylinder absent; bristles \pm uniform in length, 7–10 mm long, 0.05–0.1 mm wide, not expanded at base, plumose throughout, barbellate apical section absent, apex acute; pectines borne laterally and dorsally, 1.3–2.2 mm long at mid-bristle. Outer pappus comprising one part-whorl of 7–10 sub-plumose ensiform bristles, persistent, free, each 0.2–0.3 mm long and c. 0.05 mm wide, apex obtuse. Achenes 2.0–2.8 mm long, 0.8–1.1 mm wide, glabrous, conspicuously longitudinally ribbed, apical rim entire. (Fig. 1D, 1H, 2G).

2. *Carduus nutans* L.

Pappus monomorphic, comprising 5–7 whorls of capillary bristles, 130–169 in number, deciduous, connate to a cylinder 0.5–0.6 mm long; bristles \pm uniform in length, 15–20 mm long, 0.05–0.1 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally only, 0.04–0.1 mm long; fibrillas absent or very few, not forming a whorl, each c. 0.6 mm long. Achenes 3.3–3.8 mm long, 1.3–1.7 mm wide, glabrous, smooth, apical rim entire.

3. *Carduus pycnocephalus* L.

Pappus monomorphic, comprising 6–8 whorls of capillary bristles, 167–190 in number, deciduous, connate to a cylinder 0.6–0.7 mm long; bristles \pm uniform in length, 14–16 mm long, 0.04–0.08 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally only, 0.1–0.13 mm long; fibrillas absent. Achenes 4.8–5.3 mm long, 1.8–2 mm wide, glabrous, smooth, apical rim entire. (Fig 1C, 2A).

4. *Carduus tenuiflorus* Curtis

Pappus monomorphic, comprising 6–8 whorls of capillary bristles, 147–195 in number, deciduous, connate to a cylinder c. 0.6 mm long; bristles \pm uniform in length, 11–13 mm long, 0.04–0.08 mm

wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally only, 0.08–0.13 mm long; fibrillas absent. Achenes 4.0–4.3 mm long, 1.7–2.0 mm wide, glabrous, smooth, apical rim entire. (Fig. 2B).

5. *Carduus thoermeri* Weinm.

Pappus monomorphic, comprising 5–7 whorls of capillary bristles, 125–170 in number, deciduous, connate to a cylinder 0.4–0.6 mm long; bristles \pm uniform in length, 17–23 mm long, 0.05–0.08 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally only, 0.03–0.08 mm long; fibrillas absent. Achenes 3.5–4.1 mm long, 1.4–1.7 mm wide, glabrous, smooth, apical rim entire. (Fig. 2C).

6. *Silybum marianum* (L.) Gaertn.

Pappus dimorphic. Inner pappus comprising many fibrillas, 0.6–1.2 mm long. Outer pappus comprising 6–7 whorls of capillary bristles, 126–167 in number, deciduous, connate to a cylinder 0.4–0.8 mm long; bristles \pm uniform in length, 15–20 mm long, 0.06–0.18 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally only, 0.08–0.13 mm long. Achenes 5.6–6.7 mm long, 2.8–3.4 mm wide, glabrous, smooth, apical rim entire. (Fig. 1I).

7. *Picnomon acarna* (L.) Cass.

Pappus monomorphic, comprising 4–5 whorls of capillary bristles, 95–109 in number, deciduous, connate to a cylinder 0.4–0.6 mm long; bristles \pm uniform in length, 13–17 mm long, 0.07–0.1 mm wide, not expanded at base, plumose throughout on outer whorls, otherwise with barbellate apical section 0.8–2.2 mm long, apex acute; pectines borne laterally only, 3.0–5.2 mm long at mid-bristle; fibrillas absent. Achenes 4.6–5.2 mm long, 2.4–2.6 mm wide, glabrous, smooth, apical rim entire. (Fig. 1B, 2E, 2F).

8. *Cirsium arvense* (L.) Scop. var. *arvense*

Pappus monomorphic, comprising 3–4

whorls of capillary bristles, 57–80 in number, deciduous, connate to a cylinder 0.2–0.3 mm long; bristles \pm uniform in length, 15–22 mm long, 0.05–0.1 mm wide, not expanded at base, plumose throughout on outer whorls, otherwise with barbellate apical section 0.3–1.0 mm long, apex acute; pectines borne laterally only, 2.5–5.8 mm long at mid-bristle; fibrillas absent. Mature achenes not seen.

9. *Cirsium brevistylum* Cronquist

Pappus monomorphic, comprising 2–4 whorls of capillary bristles, 47–62 in number, deciduous, connate to a cylinder 0.25–0.3 mm long; bristles \pm uniform in length, 20–25 mm long, 0.06–0.1 mm wide, not expanded at base, plumose throughout on outermost whorl, otherwise with barbellate apical section 0.8–2.0 mm long, apex acute; pectines borne laterally only, 3.0–5.1 mm long at mid-bristle; fibrillas absent. Achenes 3.7–4.0 mm long, 1.4–1.5 mm wide, smooth, glabrous, apical rim entire.

10. *Cirsium palustre* (L.) Scop.

Pappus monomorphic, comprising 2–3 whorls of capillary bristles, 35–44 in number, deciduous, connate to a cylinder 0.2–0.3 mm long; bristles varying in length with inner exceeding outer, longer ones 8–11 mm long, 0.05–0.09 mm wide, not expanded at base, plumose throughout on outermost whorl, otherwise with barbellate apical section 0.6–1.7 mm long, apex acute; pectines borne laterally only, 0.9–2.3 mm long at mid-bristle; fibrillas absent. Achenes 3.4–3.7 mm long, 1.1–1.2 mm wide, smooth, glabrous, apical rim entire.

11. *Cirsium vulgare* (Savi) Ten.

Pappus monomorphic, comprising 2–4 whorls of capillary bristles, 38–85 in number, deciduous, connate to a cylinder 0.3–0.4 mm long; bristles \pm uniform in length, 19–28 mm long, 0.07–0.12 mm wide, not expanded at base, plumose throughout on outer whorls, otherwise with barbellate apical section 0.5–1.8 mm long, apex acute; pectines borne laterally only, 3–6 mm long at mid-bristle; fibrillas

absent. Achenes 3.5–4.0 mm long, 1.5–1.8 mm wide, smooth, glabrous, apical rim entire. (Fig. 1F, 1G)

12. *Ptilostemon afer* (Jacq.) Greuter

Pappus monomorphic, comprising 3–4 whorls of capillary bristles, 51–61 in number, deciduous, basally connate, cylinder absent; bristles \pm uniform in length, 14–17 mm long, 0.1–0.17 mm wide, not expanded at base, plumose throughout, apex acute; pectines borne laterally only, 1.5–3 mm long at mid-bristle; fibrillas absent. Achenes 4.0–4.5 mm long, 2.7–2.9 mm wide, smooth, glabrous, apical rim absent.

13. *Cynara cardunculus* subsp. *flavescens* Wiklund

Pappus monomorphic, comprising 4–5 whorls of capillary bristles, 66–93 in number, deciduous, connate to a cylinder 0.3–0.4 mm long; bristles varying in length with inner exceeding outer, longer ones 26–35 mm long, 0.15–0.25 mm wide, not expanded at base, plumose throughout on outermost whorl, otherwise with barbellate apical section 3–10 mm long, apex acute; pectines borne laterally only, or on inner whorl, pectines borne laterally and ventrally, 2.5–4.5 mm long at mid-bristle; fibrillas absent. Achenes 4.8–5.8 mm long, 3.1–3.8 mm wide, smooth, glabrous, apical rim absent.

14. *Onopordum acanthium* L.

Pappus monomorphic, comprising 2 whorls of capillary bristles, 73–119 in number, deciduous, basally connate, cylinder absent; bristles varying in length with inner exceeding outer, usually including 1–3 stout capillary bristles (9–11 mm long, 0.15–0.2 mm wide) on inner whorl; of remainder, longer ones 6.0–8.0 mm long, 0.05–0.08 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally and dorsally, 0.07–0.12 mm long. Achenes 4.1–5 mm long, 2.0–2.7 mm wide, strongly quadrangular, conspicuously transversely rugulose, glabrous, apical rim absent.

15. Onopordum acaulon L.

Pappus monomorphic, comprising 4–5 whorls of capillary bristles, 135–164 in number, deciduous, basally connate, cylinder absent; bristles \pm uniform in length, 20–25 mm long, 0.07–0.15 mm wide, not expanded at base, a small proportion fasciculate, i.e. laterally fused for one-fifth to one-half of their length, barbellate throughout, apex acute; pectines borne laterally only, or in some bristles laterally, dorsally and ventrally, 0.15–0.3 mm long. Achenes 4.0–4.5 mm long, 2.1–2.5 mm wide, strongly quadrangular, transversely rugulose, glabrous, apical rim absent.

16. Onopordum illyricum L.

Pappus monomorphic, comprising 2 whorls of capillary bristles, 61–93 in number, deciduous, basally connate, cylinder absent; bristles varying in length with inner exceeding outer, occasionally including 1 stout capillary bristle (c. 13 mm long, 0.18 mm wide) on inner whorl; of remainder, longer ones 6–11 mm long, 0.05–0.12 mm wide, not expanded at base, barbellate throughout, apex acute; pectines borne laterally and dorsally, 0.1–0.2 mm long. Achenes 4.1–6.5 mm long, 1.8–3.2 mm wide, strongly quadrangular, conspicuously transversely rugulose, glabrous, apical rim absent. (Fig. 2D).

17. Onopordum tauricum Willd.

Pappus monomorphic, comprising 2 whorls of capillary bristles, 55–84 in number, deciduous, basally connate, cylinder absent; bristles varying in length with inner exceeding outer, occasionally including 1 stout capillary bristle (9–11 mm long, 0.1–0.13 mm wide) on inner whorl; of remainder, longer ones 6–8.5 mm long, 0.04–0.08 mm wide, barbellate throughout, apex acute; pectines borne laterally and dorsally, 0.1–0.15 mm long. Achenes 4.1–4.7 mm long, 1.6–2.4 mm wide, strongly quadrangular, conspicuously transversely rugulose, glabrous, apical rim absent.

18. Arctium lappa L.

Pappus monomorphic, comprising 2–3

whorls of ensiform bristles, 80–150 in number, deciduous, all free; bristles varying in length with inner exceeding outer, longer ones 2.5–3.5 mm long, 0.07–0.1 mm wide, sub-plumose throughout, apex acute; pectines borne laterally and dorsally, 0.05–0.1 mm long. Achenes 6.9–7.3 mm long, 2.5–3.0 mm wide, faintly longitudinally striate and rugulose, glabrous, apical rim obscure, or conspicuous and coarsely sinuate.

19. Arctium minus (Hill) Bernh.

Pappus monomorphic, comprising 2–3 whorls of ensiform bristles, 60–100 in number, deciduous, all free; bristles varying in length with inner exceeding outer, longer ones 2.0–3.3 mm long, 0.07–0.1 mm wide, sub-plumose throughout, apex acute; pectines borne laterally and dorsally, 0.05–0.1 mm long. Achenes 5.2–6 mm long, 2.2–2.7 mm wide, faintly longitudinally striate and rugulose, glabrous, apical rim obscure, or conspicuous and coarsely sinuate. (Fig. 2I).

(ii) Subtribe Centaureinae**20. Carthamus dentatus Vahl**

Pappus dimorphic. Inner pappus comprising one whorl of connivent barbellate bristles, 12–13 in number, persistent, free, bristles 2.5–14 mm long (usually with 2–6 much shorter than remainder). Outer pappus comprising 4–7 whorls of ensiform bristles, 115–155 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 11–14 mm long, all 0.5–0.9 mm wide, barbellate throughout, apex acute (inner) to serrate (outer); pectines borne laterally and dorsally, 0.06–0.12 mm long. Achenes 4.5–5.8 mm long, 4.4–5 mm wide, angular, not ribbed, glabrous, apical rim entire. (Fig. 2K).

21. Carthamus lanatus L.

Pappus dimorphic. Inner pappus comprising one whorl of connivent barbellate bristles, 11–15 in number, persistent, free, bristles 0.2–1.5 mm long or 4–11 mm long. Outer pappus

comprising 4–7 whorls of ensiform bristles, 82–108 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 6.5–11 mm long, all 0.4–0.6 mm wide, barbellate throughout, apex acute (inner) to serrate (outer); pectines borne laterally and dorsally, 0.08–0.12 mm long. Achenes 4.5–5.7 mm long, 3.5–4.2 mm wide, angular, not ribbed, glabrous, apical rim entire to dentate. (Fig. 1E, 2J).

22. *Carthamus leucocaulos* Sm.

Pappus dimorphic. Inner pappus comprising one whorl of connivent sub-plumose bristles, 10–13 in number, persistent, free, bristles 1.0–4 mm long (usually with one or more much longer than remainder). Outer pappus comprising 4–6 whorls of ensiform bristles, 77–95 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 4.5–5.3 mm long, all 0.3–0.5 mm wide, barbellate throughout, apex acute (inner) to serrate (outer); pectines borne laterally and dorsally, 0.04–0.08 mm long. Achenes 3–3.5 mm long, 2.5–2.8 mm wide, angular, not ribbed, glabrous, apical rim entire.

23. *Carthamus tinctorius* L.

Pappus absent from most achenes. When present, pappus dimorphic. Inner pappus of one partial-whorl of sub-plumose ensiform bristles, 7–10 in number, persistent, free, bristles 1.3–2.6 mm long. Outer pappus comprising 4–6 partial-whorls of ensiform bristles, 13–50 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 4.5–6 mm long, all 0.2–0.3 mm wide, barbellate throughout, apex acute (inner) to serrate (outer); pectines borne laterally and dorsally, 0.07–0.12 mm long. Achenes 6.5–8 mm long, 4.1–4.7 mm wide, angular, not ribbed, glabrous, apical rim entire.

24. *Stemmacantha australis* (Gaudich.)

Dittrich

Pappus monomorphic, comprising 4–5 whorls of capillary bristles, 89–112 in number, deciduous, connate to a cylinder

0.3–0.4 mm long; bristles varying in length with outer whorl somewhat shorter than remainder, longest ones 18–23 mm long, 0.07–0.15 mm wide (outer whorls), 0.35–0.4 mm wide at base (inner whorl), sub-plumose throughout, apex acute; pectines borne laterally and dorsally, 0.8–1.6 mm long at mid-bristle; fibrillas absent. Achenes 6.5–8.4 mm long, 2.5–3.1 mm wide, longitudinally ribbed, glabrous, apical rim dentate. (Fig. 1A).

25. *Mantiscalca salmantica* (L.) Briq. & Cavill.

Pappus dimorphic. Inner pappus comprising a single tapering awn, persistent, annular at base, 3–3.5 mm long. Outer pappus comprising 4–6 whorls of ensiform bristles, 77–107 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 2.5–3.3 mm long, all 0.07–0.1 mm wide, barbellate throughout, apex acute (inner) to obtuse (outer); pectines borne laterally and dorsally, 0.04–0.08 mm long. Achenes 3.5–3.9 mm long, 1.3–1.5 mm wide, lacunose, not ribbed, glabrous, apical rim shallowly dentate. (Fig 2L, 2M).

26. *Centaurea calcitrapa* L.

Pappus absent. Achenes 2.7–2.8 mm long, 1.7–1.8 mm wide, smooth, very sparsely hairy, apical rim absent.

27. *Centaurea jacea* L.

Pappus absent. Achenes 2.7–2.9 mm long, 1.2–1.3 mm wide, faintly longitudinally ribbed, very sparsely hairy, apical rim entire.

28. *Centaurea melitensis* L.

Pappus dimorphic. Inner pappus comprising one whorl of erect or connivent barbellate ensiform bristles, 16–17 in number, persistent, free, 0.5–0.7 mm long. Outer pappus comprising 5–7 whorls of ensiform bristles, 100–150 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 2.4–3.5 mm long, all 0.05–0.08 mm wide, barbellate throughout, apex acute (inner) to obtuse (outer); pectines borne laterally and dorsally, c. 0.03 mm long. Achenes 2.6–

2.8 mm long, 1.2–1.3 mm wide, smooth, very sparsely hairy, apical rim minutely dentate. (Fig. 2H).

29. *Centaurea solstitialis* L.

Pappus dimorphic. Inner pappus comprising one whorl of erect or connivent barbellate ensiform bristles, 17–19 in number, persistent, free, 0.6–1.0mm-long. Outer pappus comprising 4–5 whorls of ensiform bristles, 70–100 in number, persistent, free; bristles varying in length with inner exceeding outer, longest ones 3.3–3.9 mm long, all 0.04–0.08 mm wide, barbellate throughout, apex acute; pectines borne laterally and dorsally, c. 0.04mm long. Achenes 2.3–2.6mm long, 1.2–1.3mm wide, smooth, very sparsely hairy, apical rim minutely dentate.

30. *Cnicus benedictus* L.

Pappus dimorphic. Inner whorl comprising one whorl of erect awns, 10 in number, persistent, free, annular at base, 2.3–3.0mm long, with coarse irregular trichomes along their length. Outer pappus comprising one whorl of erect or spreading awns, 10 in number, persistent, free, 10–11mm long, apex acute; pectines absent. Achenes 7.2–8.5mm long, 3.0–3.1 mm wide, prominently longitudinally ribbed, glabrous, apical rim conspicuously dentate.

Discussion

Bentham (1873) compared bristle *width* to pecten length to define the terms ‘plumose’ and ‘barbellate’, and this has been followed in recent times e.g. Dittrich (1968), Danin (1975), Anderberg (1991). In my opinion, these terms relate more to the bristle *length*, so that a bristle half as long as another, and with pectines half as long, is equally plumose, regardless of bristle width. The terms ‘scabrid, scabrous, rough’ and ‘denticulate’ are not here considered to be useful, as they are not significantly different from ‘barbellate’.

While I have not attempted to define a scale, they are generally considered to have a

small length-breadth ratio, are often scarious, and frequently broad-based, or with a subulate apex. Scales have not been observed in Australian or New Zealand thistles, but are reported for a few south-west Asian genera e.g. *Xeranthemum*, *Siebera*, *Chardinia* which were placed in subtribe *Carlininae* by Dittrich (1996), but transferred to subtribe *Carduinae* by Petit (1997).

Features of the pappus have been widely used by botanists to help distinguish or determine species or genera of Asteraceae, and the diversity of pappus morphology apparent in Australian and New Zealand species demonstrates their high value, but detailed studies of pappus morphology have been neglected. By contrast, there are many recent examples of studies dealing with other morphological aspects, such as pollen (Blackmore 1981, Feuer and Tomb 1977), corolla (Jeffrey 1977), ligules (Baagoe 1977), style (Jones 1976) and fruits (Källersjö 1985).

Within Australian and New Zealand *Cardueae* at least, there is a considerable morphological disjunction between capillary and ensiform bristles (as defined here), so that there is never any doubt about the application of these terms. Furthermore, most of those species with capillary bristles fall readily into either “plumose” or “barbellate” as defined here. In fact, only one species (*Stemmacantha australis*) classifies as “sub-plumose”. For ensiform bristles, only the “barbellate” and “sub-plumose” categories apply, and there is apparently a continuum of forms. Plumose ensiform bristles are not known.

It is clear from this study that pappus morphology is more or less fixed at the species level. At the generic level, the situation is less clear. Dittrich (1968) suggested that pappus characteristics often vary between species of the same genus, and hence have limited value. There is certainly infrageneric variation in *Onopordum* pappus, where some species have barbellate bristles and some are reported to have plumose bristles (Feinbrun-Dothan 1978). Nevertheless, these infrageneric differences in pappus morphology may point to other correlated differences in other parts of the plant, and hence be of phylogenetic significance.

It would be foolish to make sweeping statements about generic relationships based on this study, because of the small proportion of taxa sampled. However, a few observations may be made:

Carduus, *Silybum*, *Cirsium*, *Ptilostemon* and *Picnomon* all have pectines that are borne laterally only; the last three genera have plumose bristles. *Cynara* also seems closely related, though it has pectines borne ventrally on the bristles of the inner whorl.

Ptilostemon afer has very closely spaced pectines compared to the other plumose species in this study. The number of pectines per bristle may prove to be another useful pappus character.

Hemisteptia stands apart from all other Australian and New Zealand *Cardueae*, though it is obviously close to the Asian genus *Saussurea* DC.

The Australian representative of *Stemmacantha*, with its monomorphic pappus, deciduous capillary bristles connate to a cylinder, and the basal detachment area of the achene, seems closer to subtribe *Carduinae* than to subtribe *Centaurinae*. Its broad-based inner bristles, while distinctive, do not constitute a separate pappus type.

Centaurea, *Carthamus* and *Mantisalca* have much in common (persistent barbellate ensiform bristles, varying in length), and both *Centaurea* and *Carthamus* have a connivent inner pappus whorl.

The pappus of *Onopordum acaulon* is strikingly different from the other three Australian *Onopordum* spp. Its bristles are about twice as long as the other species, and a small proportion of them are fasciculate, although this latter feature is not obvious to the casual observer.

Key to Australian and New Zealand thistle species, based on pappus and achenes

1. Pappus present	2
Pappus absent	25
2. Pappus elements predominantly capillary bristles	3
Pappus elements predominantly ensiform bristles or awns	16
3. Bristles plumose throughout or almost throughout	4
Bristles barbellate or sub-plumose throughout	10
4. Bristles plumose throughout, cylinder absent	5
Apical section of inner bristles barbellate	6
5. Capillary bristles 14–18 in a single whorl	1. Hemisteptia lyrata
Capillary bristles 51–61, in 3–4 whorls	12. Ptilostemon afer
6. Barbellate apical section of inner bristles 3–10 mm long	13. Cynara cardunculus ssp. flavescens
Barbellate apical section of inner bristles 0.3–2.2 mm long	7
7. Cylinder 0.4–0.6mm long; achenes 4.6–5.2 mm long	7. Picnomon acarna
Cylinder 0.2–0.4mm long; achenes 3.4–4 mm long	8
8. Bristles 8–11 mm long; pectines 0.9–2.3 mm long	10. Cirsium palustre
Bristles 15–28 mm long; pectines 2.5–6 mm long	9
9. Cylinder 0.2–0.3 mm long	8. Cirsium arvense var. arvense, 9. C. brevistylum
Cylinder 0.3–0.4 mm long	11. Cirsium vulgare
10. Bristles sub-plumose	24. Stemmacantha australis
Bristles barbellate	11

11. Pappus dimorphic, inner pappus fibrillate **6. *Silybum marianum***
 Pappus monomorphic, fibrillas rare or absent 12
12. Bristles varying in length, in two whorls only
 **14. *Onopordum acanthium*, 16. *O. illyricum*, 17. *O. tauricum***
 Bristles \pm uniform in length, in 4–7 whorls 13
13. Cylinder absent, some bristles fasciculate,
 achenes quadrangular **15. *Onopordum acaulon***
 Cylinder present, bristles not fasciculate,
 achenes smooth and rounded 14
14. Bristles 15–23 mm long; pectines 0.04–0.1 mm long
 **2. *Carduus nutans*, 5. *C. thoermeri***
 Bristles 11–16 mm long; pectines 0.08–0.13 mm long 15
15. Bristles 11–13 mm long; achenes 4–4.3 mm long **4. *Carduus tenuiflorus***
 Bristles 14–16 mm long; achenes 4.8–5.3 mm long **3. *Carduus pycnocephalus***
16. Pappus comprising two whorls of awns, 10 awns per whorl **30. *Cnicus benedictus***
 Pappus wholly or predominantly of ensiform bristles 17
17. Bristles deciduous 18
 Bristles persistent 19
18. Achenes 6.9–7.3 mm long **18. *Arctium lappa***
 Achenes 5.2–6 mm long **19. *Arctium minus***
19. Inner pappus comprising a single rigid awn **25. *Mantiscalca salmantica***
 Inner pappus comprising several connivent bristles 20
20. Pappus whorls partial only; achenes 6.5–8 mm long **23. *Carthamus tinctorius***
 Pappus whorls complete; achenes 2.6–5.8 mm long 21
21. Inner pappus of 16–19 bristles; longest bristles of outer pappus
 2.4–3.9 mm long 22
 Inner pappus of 10–15 bristles; longest bristles of outer pappus
 4.5–14 mm long 23
22. Longest bristles 2.4–3.5 mm long; achenes 2.6–2.8 mm long **28. *Centaurea melitensis***
 Longest bristles 3.3–3.9 mm long; achenes 2.3–2.6 mm long **29. *Centaurea solstitialis***
23. Longest bristles 4.5–5.3 mm long; achenes 3–3.5 mm long **22. *Carthamus leucocaulos***
 Longest bristles 6.5–14 mm long; achenes 4.5–5.8 mm long 24
24. Outer pappus of 115–155 bristles, longest ones 11–14 mm long .. **20. *Carthamus dentatus***
 Outer pappus of 82–108 bristles, longest ones 6.5–11 mm long 25
25. Achenes 6.5–8 mm long **23. *Carthamus tinctorius***
 Achenes 2.3–2.8 mm long 26
26. Achenes 1.7–1.8 mm wide, smooth **26. *Centaurea calcitrapa***
 Achenes 1.2–1.3 mm wide, faintly longitudinally ribbed **27. *Centaurea jacea***

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Appendix 1 - Voucher specimens used for measurements

Arctium

A. lappa: Welsh (HO), Drake (HO); *A. minus*: Anon. 10 (HO), Curtis (HO), Grace (HO), Lampinen 5449 (BRI).

Carduus

C. nutans: Bloomfield s.n. (MEL), Morris s.n. (HO), Doing s.n. 18/4/67 (CANB); *C. pycnocephalus*: Bean 15672 (BRI), Bean 15738 (BRI); *C. tenuiflorus*: Vonow 98 (AD), Whinray 607 (AD), Whibley 3723 (AD); *C. thoermeri*: Bean 15589 (BRI), Bean 15892 (BRI), Bean 15914 (BRI).

Carthamus

C. dentatus: Gray & Medway 7083 (BRI), Howlett s.n. (MEL); *C. lanatus*: Adams s.n. (BRI), Blake 5164A (BRI), Alcock 5556 (AD), Coveny 16368 & Whalen (BRI); *C. leucocaulos*: Hunt 1872 (AD), Overton 767 (AD); *C. tinctorius*: Moore s.n. (BRI), A.E.Smith s.n. (BRI).

Centaurea

C. calcitrapa: R.V.Smith 68/29 (BRI); *C. jacea*: Bird s.n. 29/4/89 (BRI); *C. melitensis*: Bean 15890 (BRI), L.S.Smith 3047 (BRI); *C. solstitialis*: Bean 14774 (BRI), Everist 4286 (BRI).

Cirsium

C. arvense var. *arvense*: Curtis s.n. (HO), Reid 2167 (MEL), Morrison s.n. (CANB), Scarlett 82-15 (CANB); *C. brevistylum*: Worsley s.n. 11/1/72 (CHR), Anon. [CHR 5714B] (CHR); *C. palustre*: Holm-Nielsen 330 et al. (BRI); McLaren s.n. (CHR). *C. vulgare*: Buchanan 750 (HO), Cummings 97 (CANB), Jobson 4575 et al. (BRI).

Cnicus

C. benedictus: Hoffman s.n. (CANB), Clydesdale s.n. (BRI).

Cynara

C. cardunculus ssp. *flavescens*: Ising s.n. (AD), Wilson 3600 (AD).

Hemisteptia

H. lyrata: K.McDonald s.n. (BRI), Jones 2908 (CANB).

Mantisalca

M. salmantica: Bean 15637 (BRI); Mansbridge s.n. (BRI).

Onopordum

O. acanthium: Cleland s.n. (AD), Ward s.n. (HO), Fitzpatrick ONO9 (CANB), Michael 29/12/69 (CANB); *O. acaulon*: H.W.Andrew (AD), Bartsch 5 (AD), Beaglehole 87638 & Huebner (MEL), Symon 1886 (AD); *O. illyricum*: Alcock 4977 (AD), Colwill ONO17 (CANB), Somneville ONO18 (CANB), Nelligan ONO19 (CANB); *O. tauricum*: Alcock 6151 (AD), Gebert s.n. (MEL).

Picnomon

P. acarna: Symon 2095 (AD), Amtsberg s.n. (AD), Copley 1106 (AD).

Ptilostemon

P. afer: E.G.Smith s.n. (CHR).

Silybum

S. marianum: Bean 15605 (BRI), Bean 15806 (BRI), Bean 15829 (BRI).

Stemmacantha

S. australis: Fensham 1396 (BRI), Bean 11348 (BRI), Bartlam s.n. (BRI).